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A Post-processing Technique for the Improvement of Color Blurring Using Modulations of Chroma AC Coefficients in DCT-coded Images

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ABSTRACT

In this paper, we propose a post-processing technique developed for the subjective improvement of color resolution in DCT-coded color images. The high frequency components caused by complex object parts are compressed and impaired through DCT-based image processing, so color distortions such as blurs in high saturated regions are observed. It's mainly due to the severe loss of color data as *Cb* and *Cr*. Generally, the activities of chroma elements in DCT domain correlate strongly with that of luminance as spatial frequency gets higher, and based on the relations between chroma and luma AC activities, we compensate destructed *Cb*, *Cr* coefficients using modifications from *Y* coefficients. Simulation results show that the proposed method enhances color resolution in high saturated region, and improves the visual quality.

Key words: DCT, Decimation, Quantization, Color Resolution

1. INTRODUCTION

Most of the international standards for image and video compression, such as JPEG [1], H.261 [2], H.263 [3], and MPEG recommend [4,5] are based on a lossy DCT(discrete cosine transform)-based compression technique. In a practical compressed image, many factors lessen the color contrast and impair perceived picture quality. Many kinds of artifacts in compression images have been presented, and especially these exhibit highly noticeable degradations at very low bit rates for transmission. In these, blocking effect, mosquito noise, and bleeding effect are the most well-known ones, and several processing methods for improvement have been proposed [6-8].

Nevertheless, another type of artifacts has been rarely considered in color image processing. It's the reduction of color resolution by a narrower color bandwidth relatively compared with that of luminance. This distortion appears as color blurring(or smoothing) in the high saturated images. The higher chroma regions in pictures do appear brighter, so perceived brightness increases with increasing color saturation. This effect can be illustrated by the Helmholtz-Kohlrausch effect [9]. The distortion in higher chrominance elements gives severe offense to visual sense. This phenomenon results from lower sampling frequency and sparser quantization of the higher order AC coefficients for color elements [7,8]. The color smoothing is well shown in upper body in Fig. 1(b).

In this paper, we proposed a modification method of chrominance DCT coefficients to enhance the visual color resolution in high chroma images at low bit rates. First, the correlation among DCT coefficients in luminance and chrominance blocks was analyzed. The activities of chrominance ac el-

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(a) (b)

Fig. 1. Effect of the color blurring: (a) an original image, (b) a DCT-coded image.

ements in DCT domain correlate strongly with that of luminance. The activity sums of chrominance blocks are in proportion to the those of luminance blocks in higher spatial frequency. Then we compensated the destructed higher order AC coefficients of chrominance block using estimated ones by the proposed method, which consists of two parts, polarity estimation and weighted value estimation of coefficients. Basically, polarity and weighting are derived from the information of reconstructed Y blocks. It could be found in reconstructed images that the proposed post-processing method improves the subjective quality of high colored images.

2. ANALYSIS OF COLOR DISTORTION IN DCT-CODED IMAGES

Color images are generally represented by three color components. Even though the choice of the color space used in JPEG is not specialized, the color images are generally converted from the *RGB* color space to the *YCbCr* one before being encoded, where Y is the luminance part and *Cb* and *Cr* are the chrominance part of image. The compression algorithm is applied independently to each of the three components in the same way. However, since the human visual system is less sensitive to colored details, the chrominance parts are subsampled by a factor of two in the horizontal dimension in the 4:2:2 format or by a factor of two in both the horizontal and vertical dimensions in the 4:2:0 format [10], and coarse quantization of color elements could be usually used through quantization tables shown in Table 1. The factors in tables are applied in order to strengthen compression.

The DCT coefficients of *Cb* and *Cr* tend to be removed because of the coarse quantization during encoding and color components are more corrupted in relatively higher frequency. Fig. 1 shows an color blurring in high saturated region of the reconstructed image, and the distortion of color elements on a player's body is visible.

This existing occurrence can be illustrated from changes observed in DCT coefficients through JPEG en-decoding. Fig. 2 shows differences in the activity distributions of DCT blocks before and after

(a)

16	11	10	16	24	40	51	61
12	12	14	19	26	58	60	55
14	13	16	24	40	57	69	56
14	17	22	29	51	87	80	62
18	22	37	56	68	109	103	77
24	35	55	64	81	104	113	92
49	64	78	87	103	121	120	101
72	92	95	98	112	100	103	99

(b)

17	18	24	47	99	99	99	99
18	21	26	66	99	99	99	99
24	26	56	99	99	99	99	99
47	66	99	99	99	99	99	99
99	99	99	99	99	99	99	99
99	99	99	99	99	99	99	99
99	99	99	99	99	99	99	99
99	99	99	99	99	99	99	99

Table 1. Quantization arrays: (a) Y components, (b) *Cb* and *Cr* components.

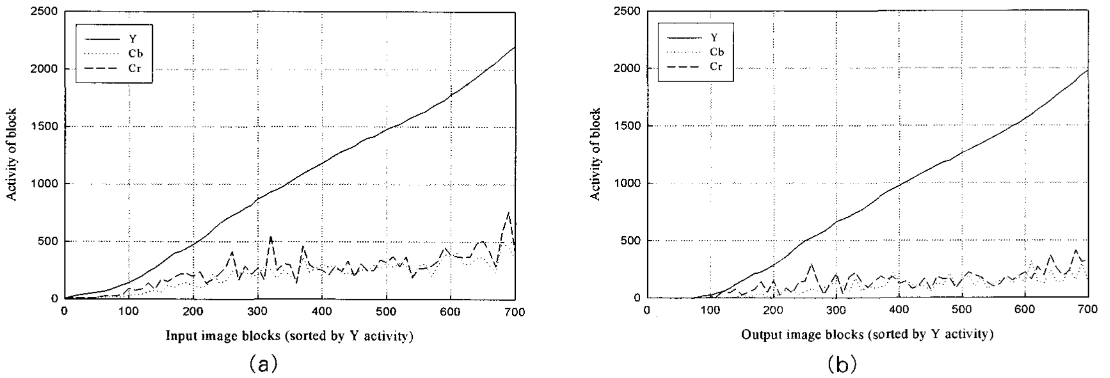

Fig. 2. Comparison of activity distribution in DCT blocks: (a) Before quantization, (b) After de-quantization.

processing in table-tennis image. The activity of a block is defined by Eq. 1. First, luminance blocks are ordered as activity values calculated, then the distribution of chrominance blocks corresponding to each luminance block is plotted.

$$Activity\ of\ block = \sum_{i=0}^{N-1}\sum_{j=0}^{N-1} DCT\ block[i][j] - DC\ element \quad (1)$$

where N is a block size. (e.g., $N = 8$), DCT $block[i][j]$ is a coefficient value correspond to i'th of x-axis and j'th of y-axis, and a DC element of block is the first element in a block, DCT $block[0][0]$.

Fig. 2(a) shows the activity distributions of input coefficients in Y, Cb, and Cr blocks before divided by quantization factors. Due to subsampling of color elements, chrominance activities are relatively low when compared with luminance ones. Fig. 2(b) shows the activity distribution of reconstructed coefficients. The information of about 50% ~ 60% for Cb and Cr blocks is lost in DCT domain. The total distortion of chrominance is related to both decimation and quantization processes [8]. The resulting coefficients of DCT are divided by quantization factors, and then quantized. When quantized inversely, most of the components in high order frequency are reduced.

Fig. 3 shows changes in the relating ratio of Cb and Cr activities to Y activities. As a spatial frequency gets higher, the activity values of

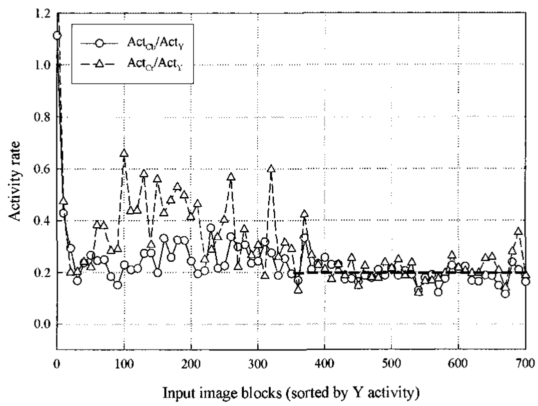

Fig. 3. Changes in the relating ratio of Cb and Cr activities to Y activities.

chrominance blocks are in proportion to the those of luminance blocks. We assume that the sample points related to the ratio between luminance and chrominance activities lie close to the constant value. The value of 0.2 is available to make a progress line. As shown in Fig. 2, Y signals are well transported relatively. Based on these results, we develop a technique for compensating color elements using the information of Y elements in DCT domain in order to increase the visual quality of reconstructed digital color images.

3. A PROPOSED MODIFICATION METHOD FOR DCT COEFFICIENTS

We consider the case of chrominance signals that have been 4:2:0 down-sampled by a factor of two, in both horizontal and vertical directions, because this video format is the most employed in digital video compression algorithms (in MPEG-1, 2 or H.263). In the case of 4:2:0 chrominance signals, a macro block contains four blocks of *Y*, one of *Cb* and one of *Cr*, respectively.

3.1 Detection of chrominance blocks subject to color smoothing

In the previous section, the reason causing reduction of color resolution has been analyzed, and we have seen the correlation between luminance activity and chrominance one in the same block. For natural images, a strong chrominance contrast is accompanied by strong luminance contrast [11], There is a strong relationship among *Y*, *Cb*, and *Cr* coefficients at higher levels of spatial frequency shown as Fig. 3.

The flow diagram of an our postprocessor is shown in Fig. 4. The proposed method can be divided into two main steps: the first one is for detecting the blocks subject to the color smoothing seen well subjectively. Then these selected blocks are processed in the second part of algorithm in order to enhance color resolution.

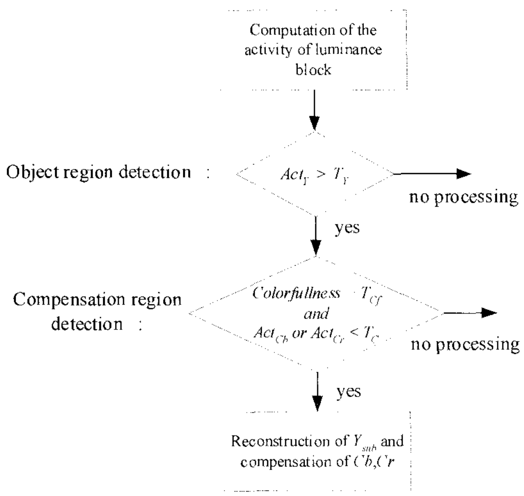

Fig. 4. Flowchart of the proposed post-processor.

As a first step, object regions containing strong luminance edges are detected through the luminance activity (Act_Y) calculated by Eq. (1), and we compute the chrominance activity of each block (Act_{Cb}, Act_{Cr}) and the colorfulness of object blocks. In order to select more visually perceptible regions, the colorfulness is used as Eq. (2).

$$Colorfullness = |Cb[0][0]| + |Cr[0][0]| \qquad (2)$$

where *Cb*[0][0] is a DC element of *Cb* block, and *Cr*[0][0] is a DC element of *Cr* block.

Because significant edges of the chrominance part usually correspond to the higher detailed regions of the luminance part, *Cb* and *Cr* blocks having relatively less activity in object blocks are chosen to be compensated effectively. The threshold T_Y, T_C, and T_{Cf} which used in processing can be controlled to reduce computing burden or enhance success rate of estimation. The graphs in Fig. 3 contribute to decide the value of T_Y. Suitable compensation regions are decided in the range of *Y* activities which have strong correlations with *Cb*, *Cr* activities. At higher levels of frequency, compensations for impaired chrominance coefficients would be useful. Also for an efficient processing, more detectable regions should be selected for the enhancement of perceived picture quality. In this study, the thresholds for detecting object and compensation region were obtained experimentally and could be applied to general color images. (the thresholds: T_Y = 100, T_C = 350, and T_{Cf} = 200)

Common regions of objects and compensation marked are shown in Fig. 5. *Cb*'s and *Cr*'s DCT coefficients in the region including both regions in common will be compensated.

3.2 Enhancement of Color Resolution in Detection Regions

Fig. 6 illustrates the compensation processing for *Cb* and *Cr* blocks coded by DCT. First, the 16×16 macro block of luminance elements, made

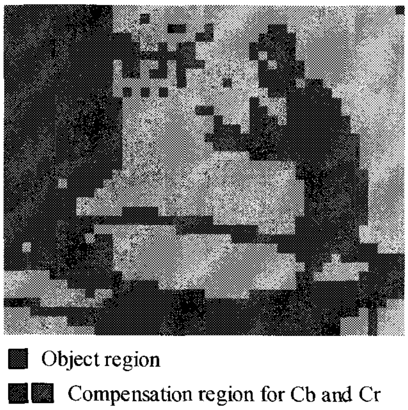

Fig. 5. Result of detection for object and compensation region in the table-tennis image. (the thresholds: T_Y = 100, T_C = 350, and T_{Cf} = 200)

from four adjacent blocks of 8×8 pixels in the selected compensation region is decoded. After inverse DCT, these are subsampled to a 8×8 block, and reconstructed to a 8×8 luminance sub-DCT block (Y_{sub}). Luminance DCT components corresponding to the same spatial region of chrominance ones to be compensated are obtained through this process. Second, Luminance elements to be transplanted to chrominance blocks are selected and modified through multiplication by two kinds of factor, the first one is for phase polarity, and the other is a weighted coefficient value. Then the modified coefficients (Cb_C, Cr_C) for compensation are added to the position of lost coefficients.

For efficient estimation of coefficient's polarity, first harmonics of coefficients in DCT table are referred as described in Fig. 6(b). Five regions associating horizontal, vertical, and diagonal directions are divided except high order frequency parts and coefficients' polarity belong to each region is estimated by a conditional equation of Eq. (3). Next, the weighted factor meaning main activity ratio between luminance elements and chrominance ones is calculated. As described in the previous section, there is a huge difference in activity with luminance

$$\begin{array}{l}
P = 1\,(positive : default\ polarity) \\
case\ division\ of\ P(a): \\
\quad if\,(Y_{sub}[1][0] \times B[1][0] < 0) \\
\qquad P = -1\,(negative) \\
case\ division\ of\ P(b): \\
\quad if\,(Y_{sub}[0][1] \times B[0][1] < 0) \\
\qquad P = -1\,(negative) \\
case\ division\ of\ P(c): \\
\quad if\,(Y_{sub}[1][1] \times B[1][1] < 0) \\
\qquad P = -1\,(negative) \\
case\ division\ of\ P(a,c): \\
\quad if\,(B[1][0] > B[1][1])\ and\ (Y_{sub}[1][0] \times B[1][0] < 0) \\
\qquad P = -1\,(negative) \\
\quad else\ if\,(B[1][0] < B[1][1])\ and\ (Y_{sub}[1][1] \times B[1][1] < 0) \\
\qquad P = -1\,(negative) \\
case\ division\ of\ P(b,c): \\
\quad if\,(B[0][1] > B[1][1])\ and\ (Y_{sub}[0][1] \times B[0][1] < 0) \\
\qquad P = -1\,(negative) \\
\quad else\ if\,(B[0][1] < B[1][1])\ and\ (Y_{sub}[1][1] \times B[1][1] < 0) \\
\qquad P = -1\,(negative)
\end{array} \tag{3}$$

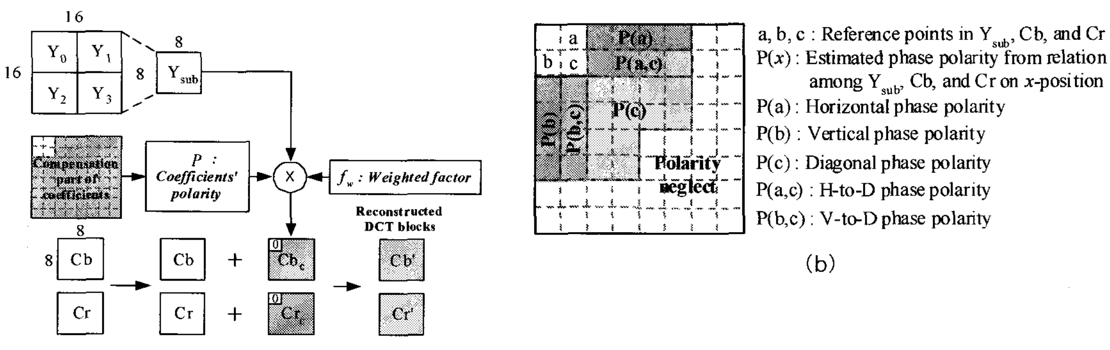

Fig. 6. Illustration of a compensation processor for *Cb*, *Cr* blocks: (a) a processing flow, (b) division and reference points for the estimation of coefficients' phase polarity.

ones after DCT process. The coefficient elements of luminance applied to chrominance block have to be arbitrated to meet the balance of activity between luminance and chrominance, therefore first harmonics coefficients of one and two dimensions are used to obtain the ratio as Eq. (4).

The conditional equations to complete compensation for each Cb and Cr blocks are presented in Eq. (5) and (6). Finally, components vanished in the process of quantization are reconstructed but except nonzero ones.

$$f_w(B) = \frac{\sum_{i=0}^{1}\sum_{j=0}^{1}|B[i][j]| - |B[0][0]|}{\sum_{i=0}^{1}\sum_{j=0}^{1}|Y_{sub}[i][j]| - |Y_{sub}[0][0]|} \quad for\ \mathrm{neq}(0) \tag{4}$$

$$\begin{aligned} & if(\,i>1\ or\ j>1)\ and\ (Cb[i][j]==0) \\ & \quad Cb'[i][j] = P\times f_w(Cb)\times Y_{sub}[i][j] \\ & else \\ & \quad Cb'[i][j] = Cb[i][j] \end{aligned} \tag{5}$$

$$\begin{aligned} & if(\,i>1\ or\ j>1)\ and\ (Cr[i][j]==0) \\ & \quad Cr'[i][j] = P\times f_w(Cr)\times Y_{sub}[i][j] \\ & else \\ & \quad Cr'[i][j] = Cr[i][j] \end{aligned} \tag{6}$$

where P is a polarity factor and $f_w(B)$ is a weighted factor for block B (B is Cb or Cr), Y_{sub} is a block for luminance, and Cb', Cr' are final blocks compensated.

4. EXPERIMENTAL RESULTS

Computer simulations were carried out on some color images, in order to demonstrate the effectiveness of the proposed post-processing algorithm. The performance was mainly evaluated by visual judgment, because there was no effective measurement available. The peak signal-to-noise ratio (PSNR) was used for objective evaluation, but it is not well correlated with the properties of human color vision, and in this case, PSNR computed on the whole image does not reflect the localized improvement of our processing algorithm. The improvement in PSNR for Cb, Cr each was so feeble shown as Table 2. (about 0.1 dB over whole image regions). Table 3 shows the performance of coefficients' polarity estimation in test images, table-tennis and flower image. For the region which polarity is considered in, accuracy of estimation is about 70-80 %.

Table 2. Performance in PSNR of the proposed method.

Test image	Table-tennis	Flower
$\Delta PSNR$ for R component	+0.12 (dB)	+0.08 (dB)
$\Delta PSNR$ for G component	+0.01 (dB)	+0.02 (dB)
$\Delta PSNR$ for B component	0	0

Table 3. Estimation performance of coefficients' polarity.

Division	Estimation accuracy (%)
$P(A)$	72.1
$P(B)$	71.7
$P(C)$	74.5
$P(A,C)$	85.8
$P(B,C)$	69.8
Total region	74.6

Fig. 7(b), Fig. 7(d), and Fig. 7(f) show the result of color resolution enhancement for images. It is very noticeable that color resolution has been improved in high frequency and high chroma regions. This is obviously true in high special frequency regions in Fig. 7(b), the player's body, and the flower's stamen, where the shape of color shadow is restored. As already mentioned, this result is to be considered visually reasonable, and it's the aim of the processing technique to reduce the visual impact of the color distortion.

5. CONCLUSIONS

In this paper, we proposed a post-processing method to enhance the color resolution only using

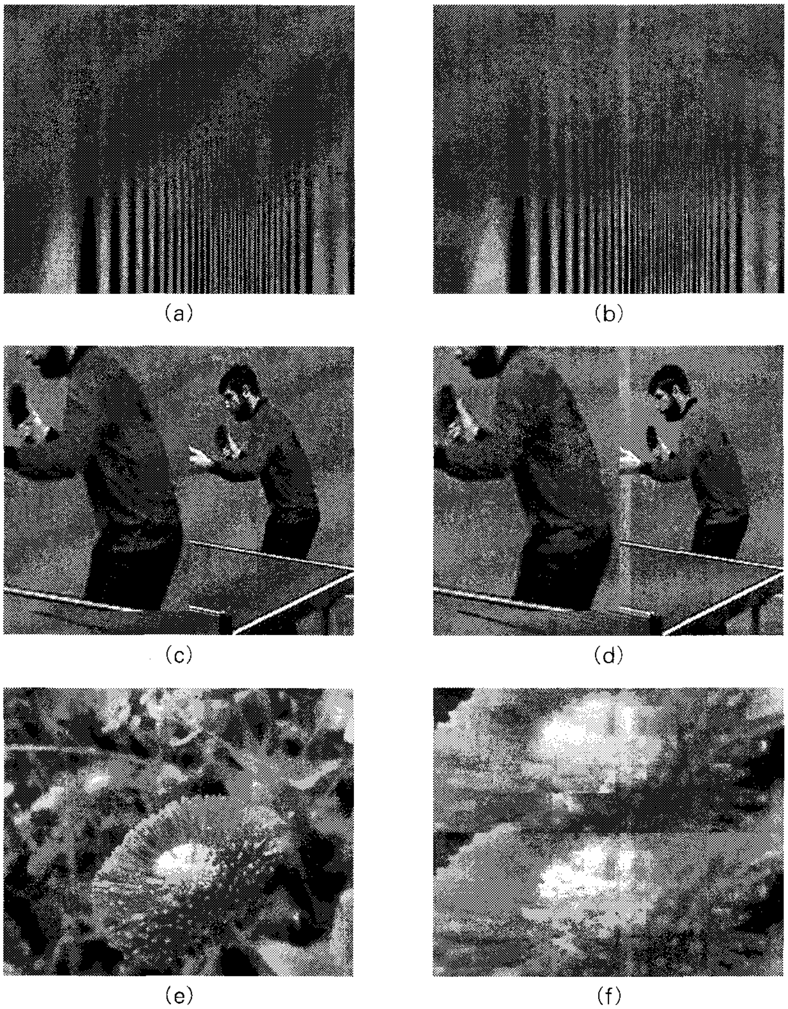

Fig. 7. Comparisons of image quality between an original image and an image with proposed post-processing: (a) a reconstructed image 1 without post-processing, (b) with post-propossing, (c) a reconstructed image 2 without post-processing, (d) with post-propossing, (e) an input image 3, (f) Enlarged portion of coded image before and after post-processing (upper part is old, and lower part is new).

modified DCT coefficients in digital color images or video sequences. After the decimation and quantization, most of the chrominance coefficients are destructed at low bit rates, and color resolution become reduced in view of infallible experimental results. In order to enhance color resolution in high saturated images, we have to compensate the corrupted chrominance data. The activities of luminance and chrominance in same block are proportioned with each other at higher spatial frequency, and it is expected that chrominance blocks belongs to high-detailed areas are relatively more distorted.

The proposed algorithm consists of two steps. First, visually corrupted color region is selected from object blocks, and then we compensated the higher order AC coefficients of chrominance block using polarized and weighted luminance coefficients based on correlation in DCT coefficients. Images reproduced with compensated coefficients show the enhanced performance for perceived picture quality.

It could be integrated in a more general digital video processing system, including the reduction of other kinds of artifacts and contribute to the improvement of the subjective visual quality of color images to reduce color blurs of DCT-based compression images.

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